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Raytheon

Raytheon STX Corporation

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Nimbus/TOMS Science Data Operations Support

FINAL REPORT

July 1992 – May 1998
NASA Contract No. NAS5-31755

Raytheon

Raytheon STX Corporation

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May 11, 1998

Ms. Veronica Stubbs
NASA GSFC
Contract Specialist, Code 219
Building 16, Room 224
Greenbelt, MD 20771-0001

Subject: Final Contract Report/ Contract NAS5-31755 (Raytheon STX No. 3036)
POP: July 1992 – May 1998 (Base and Extension)

Dear Ms. Stubbs:

In accordance with Revision No. 48 of Contract NAS5-31755, enclosed please find the Final Contract Report .

If you have any questions or comments regarding this deliverable, please contact me at 301-441-4021.

Sincerely,



Jeff Childs
Program Manager

Enclosures

cc: COTR, Code 916
Publications & Graphics, Code 253.1

FINAL REPORT - UV Remote Sensing Project

July 1992 - May 1998
Contract No. NAS5-31755

NASA GSFC COTR: Dr. J. Herman
Raytheon STX Program Manager: Dr. J. Childs
Raytheon STX Task Leaders: Mr. W. Byerly, Dr. R. Cebula, Mr. C. Wellemeyer

CONTRACT MISSION STATEMENT:

The contractor shall: (1) participate in and provide analysis of laboratory and in-flight calibration of UV sensors used for space observations of backscattered UV radiation; (2) provide support to the TOMS Science Operations Center, including generating instrument command lists and analysis of TOMS health and safety data; (3) develop and maintain software and algorithms designed to capture and process raw spacecraft and instrument data, convert the instrument output into measured radiance and irradiances, and produce scientifically valid products; (4) process the TOMS data into Level 1, Level 2, and Level 3 data products; and (5) provide analysis of the science data products in support of NASA GFSC Code 916's research.

WORK PERFORMED:

Missions Supported

Raytheon STX Corporation (RSTX) supported the following missions, covering the data periods listed in parenthesis, during the period July 1992 through May 1998:

- Nimbus-7 SBUV, TOMS, ERB, and SAM II (October 1978 - May 1993)
- Meteor-3 TOMS (August 1991 - December 1994)
- ADEOS TOMS (August 1996 - June 1997)
- Earth Probe (EP) TOMS (July 1996 - present)
- NOAA-9 SBUV/2 (December 1984 - February 1998)
- NOAA-11 SBUV/2 (September 1988 - April 1995)
- NOAA-13 SBUV/2 (August 1993)
- NOAA-14 SBUV2 (December 1994 - present)
- SSBUV (Eight missions, October 1989 - January 1996, including four flights during the current period of performance)

Instrument Calibration and Characterization

RSTX analysts supported the prelaunch calibrations of the Meteor-3, ADEOS and EP TOMS, and the NOAA-14 SBUV/2 instruments. Support was also provided for the prelaunch calibrations of SBUV/2 Flight Model units numbers 3, 6, and 7 (these sensors are scheduled to fly on future NOAA operational spacecraft from approximately 1999 through the first decade of the next century). RSTX personnel participated in the acquisition of calibration data at the instrument vendors' sites and provided detailed analysis of all spectroradiometric calibration data. Prelaunch and postlaunch calibration analysis was also provided for each SSBV mission. Key accomplishments and findings included:

- Determined errors in the vendor-supplied Meteor-3, ADEOS and EP wavelength calibrations.
- Developed a new technique to improve the accuracy of fitting procedures used with NIST-supplied lamp calibrations.
- Developed a method to evaluate the long-term stability of D₂ lamps via comparisons with other, more stable sources in conjunction with sensor data.
- Supported research and development of new laboratory radiance targets - specifically, the use of integrating sphere targets.

RSTX provided analysis of calibration and characterization data from each of missions previously listed. This included analyzing initial checkout (Activation and Evaluation Phase) data, monitoring instrument health and safety, and characterizing long-term sensor degradation on-orbit. Where sensor performance problems were identified, RSTX personnel worked with Government and other contractor personnel to create "work-arounds" in order to maximize sensor lifetime and minimize impact to the science data products. Key accomplishments and findings included:

- Evaluated the impact of attitude errors on the TOMS spacecraft.
- Developed techniques to use solar data as a wavelength calibration source for the TOMS, SBUV/2, and SSBUV instruments.
- Analyzed A & E phase data from the ADEOS and EP TOMS and the NOAA-14 SBUV/2 instruments.
- Monitored housekeeping data from all SBUV and TOMS instruments.
- Determined long-term calibrations for the Nimbus-7, Meteor-3, ADEOS, and EP TOMS instruments.
- Created and enhanced methodology to derive each instrument's goniometric characterization using inflight data.
- Provided the Version 6.1 calibrations for the NOAA-9 and NOAA-11 sensors.
- Supported four SSBUV Shuttle missions in April 1993, March 1994, November 1994, and January 1996. RSTX support included mission simulations, mission planning and preparation, and mission operations.
- Used SSBUV underflights of the NOAA-9 and NOAA-11 SBUV/2 instruments to determine their absolute calibrations and validate their long-term characterizations.
- Developed a technique to use the sun as a vicarious calibration source in order to evaluate short-term sensor changes.
- Developed use of ice radiances for long-term sensor changes.
- Evaluated the NOAA-14 SBUV/2 CCR failure.
- Monitored, evaluated, and created work-arounds for NOAA-14 SBUV/2 grating drive errors.
- Supported EP TOMS "stare mode" operations.

Results of RSTX's calibration work are documented in the following Contractor Reports, NASA Reference Publications, and journal papers:

Ahmad, Z., M. T. DeLand, R. P. Cebula, H. Weiss, C. G. Wellemeyer, W. G. Planet, J. H. Lienesch, H. D. Bowman, A. J. Miller, and R. M. Nagatani, "Accuracy of Total Ozone Retrieval from NOAA SBUV/2 Measurements: Impact of Instrument Performance", *J. Geophys. Res.*, 99, 22975-22984, 1994.

Byerly, W., G. Jaross, C. Seftor, "Meteor-3/TOMS First Year Data Processing", HSTX-3036-114-GJ-92-019, December 1992.

- Cebula, R. P., E. Hilsenrath, P. W. DeCamp, K. Laamann, S. Janz, and K. McCullough, "The SSBUV Experiment Wavelength Scale and Stability: 1988 to 1994", *Metrologia*, 32, 633-636, 1996.
- Cebula, R. P., L.-K. Huang, and E. Hilsenrath, "SSBUV Sensitivity Drift Determined Using Solar Spectral Irradiance Measurements", *Metrologia*, in press, 1998.
- DeCamp, P., "Coherent Range Two 'Noise' Observed during the Pre SSBUV-5 Sweep Mode FEL Calibration Tests", HSTX-3036-212-PD-94-005, February 1994.
- DeLand, M. T., and R. P. Cebula, "NOAA-11 Inflight Goniometric Correction Update", HSTX-3036-501-MD-96-008, June 1997.
- DeLand, M. T., and R. P. Cebula, "Derivation of the NOAA-11 In-Flight Goniometric Correction", HSTX-3036-112-MD-93-020, April 1993.
- DeLand, M. T., K. Laamann, and R. P. Cebula, "NOAA-14 (FM#5) SBUV/2 Activation and Evaluation (A&E) Phase Final Report", HSTX-3036-401-MD-95-015, August 1995.
- DeLand, M. T., K. Laamann, and R. P. Cebula, "NOAA-11 SBUV/2 Calibration Revisions for Version 6 Ozone Reprocessing", HSTX-3036-112-MD-93-031, July 1993.
- DeLand, M., and K. Laamann, "NOAA-9 SBUV2 Instrument Characterization Update", HSTX-3036-212-MD-94-012, August 1994.
- DeLand, M. T., H. Weiss, R. P. Cebula, and K. Laamann, "NOAA-9 and NOAA-11 SBUV/2 Wavelength Scale Drift", HSTX-3036-112-MD-92-013, October 1992.
- Heath, D. F., and Z. Wei, "Determination of the Spectral Radiance Calibration of the Spherical Integrator Using the SSBUV Instrument and Derived Spectral Radiance, Irradiance, and Albedo Calibration Constants", HSTX-3036-112-DH-93-028, April 1993.
- Heath, D. F., and Z. Wei, "Measurement of Average BRDF of Large Area Diffuser Panels Derived Using the Internally Illuminated Spherical Integrator for Spectral Radiance Calibration", HSTX-3036-112-DH-93-027, April 1993.
- Hilsenrath, E., R. P. Cebula, M. C. Bories, J. J. Cerullo, P. W. DeCamp, L.-K. Huang, C. N. Hui, S. J. Janz, T. J. Kelly, K. R. McCullough, J. J. Mederios, J. T. Riley, B. K. Rice, and C. D. Thorpe, "Contributions of the SSBUV Experiment to Long-Term Ozone Monitoring", *XVIII Quadrennial Ozone Symposium*, Vol. I, 49-52, 1998.
- Hilsenrath, E., P. K. Bhartia, and R. Cebula, "Calibration of BUV Satellite Ozone Data - An Example for Detecting Environmental Trends", in Workshop on Strategies for Calibration and Validation of Global Change Measurements: May 10-12, 1995, NASA Reference Publication 1397, B. Guenther, J. Butler, and P. Ardanuy eds., NASA Goddard Space Flight Center, Greenbelt, MD, pp. 58-66, April 1997.
- Hilsenrath, E., P. K. Bhartia, R. P. Cebula, and C. Wellemeyer, "Calibration and Intercalibration of BUV (Backscatter Ultraviolet) Satellite Ozone Data", *J. Adv. Space Res.*, 19, 1345-1353, 1997.

- Hilsenrath, E., J. Gleason, S. Janz, X-y Gu, R. P. Cebula, K. Chance, and R. Hoekstra, "GOME Calibration and Validation Using Backscatter UV Techniques", GOME Geophysical Validation Campaign: Final Results and Workshop Proceedings, P. Fletcher and F. Lodge, eds., European Space Agency WPP-108, April 1996.
- Hilsenrath, E., P. A. Newman, R. P. Cebula, P. W. DeCamp, T. J. Kelly, and L. Coy, "Ozone Depletion from 1992 to 1993 As Observed from SSBUV on the ATLAS-1 and ATLAS-2 Missions", *Geophys. Res. Lett.*, 23, 2305-2308, 1996.
- Hilsenrath, E., R. P. Cebula, M. T. DeLand, K. Laamann, S. Taylor, C. Wellemeyer, and P. K. Bhartia, "Calibration of the NOAA-11 SBUV/2 Ozone Data Set from 1989 to 1993 Using In-Flight Calibration Data and SSBUV", *J. Geophys. Res.*, 100, 1351-1366, 1995.
- Hilsenrath, E., P. K. Bhartia, and R. P. Cebula, "Calibration of BUV Satellite Ozone Data - An Example for Detecting Environmental Trends", *The Earth Observer*, 6, 26-33, 1994.
- Hilsenrath, E., R. D. McPeters, and R. P. Cebula, "Status of the Shuttle SBUV Calibration of the NOAA SBUV/2 Operational Ozone Sounders and the Detection of Trends," Ozone in the Troposphere and Stratosphere, Part 2, R. D. Hudson, ed., NASA Conference Publication 3266, 883-886, 1994.
- Hilsenrath, E., D. E. Williams, R. T. Caffrey, R. P. Cebula, and S. J. Hynes, "Calibration and Radiometric Stability of the Shuttle Solar Backscatter Ultraviolet (SSBUV) Experiment", *Metrologia*, 30, 243-248, 1993.
- Huang, L. K., "A New Procedure for SSBUV Albedo Calibration Based on the Integration Sphere Measurements", HSTX-3036-508-LH-96-014, December 1997.
- Huang, L. K., "Using SSBUV Quartz Diffuser Transmission Spectral Profile for SSBUV Albedo Calibration from 200 nm to 250 nm", HSTX-3036-508-LH-96-021, August 1996.
- Huang, L. K., and R. P. Cebula, "A Function Fitting Procedure for Interpolation of NIST Deuterium Lamp Irradiance Calibrations", HSTX-3036-701-LH-97-020, September 1997.
- Huang, L. K., and R. P. Cebula, "SSBUV Sensitivity Drift during Flight Determined Using Solar Irradiance Measurements", HSTX-3036-508-LH-96-015, September 1997.
- Huang, L. K., and R. P. Cebula, "Irradiance Drifts of SSBUV Deuterium Lamps", HSTX-3036-508-LH-97-013, August 1997.
- Huang, L. K., R. P. Cebula, and E. Hilsenrath, "Determination of Deuterium Lamp Irradiance Drifts in the SSBUV Laboratory", *Metrologia*, in press, 1998.
- Huang, L. K., R. P. Cebula, and E. Hilsenrath, "New Procedure for Interpolating NIST FEL Lamp Irradiances", *Metrologia*, in press, 1998.
- Janz, S., E. Hilsenrath, J. Butler, D. F. Heath, and R. P. Cebula, "Uncertainties in Radiance Calibrations of Backscatter Ultraviolet (BUV) Instruments as Determined from Comparisons of BRDF Measurements and Integrating Sphere Calibrations", *Metrologia*, 32, 637-641, 1996.

- Jaross, G., A. Krueger, R. P. Cebula, C. Seftor, U. Hartmann, R. Haring, and D. Burchfield, "Calibration and Postlaunch Performance of the Meteor-3/TOMS Instrument", *J. Geophys. Res.*, 100, 2985-2996, 1995.
- Jaross, G., A. Krueger, and C. Wellemeyer, "Diffuser Reflectance Requirements For TOMS Version 7 Products, *Metrologia*, in press, 1998.
- Jaross, G., and A. Krueger, "Ice Radiance Method For Backscatter UV Instrument Monitoring", *Proc. SPIE*, 2047, 94-101, 1993.
- Jaross, G., A. Krueger, H. Park, and R. Haring, "Improved Ozone Trend Measuring Capabilities of TOMS Instruments", *Proc. SPIE*, 2831, 48-56, 1996.
- Jaross, G., "M3 TOMS Attitude Errors", HSTX-3036-503-GJ-96-018, May 1996.
- Jaross, G., and A. Krueger, "Multi-Spectral Calibration of Remote Sensing Instruments Over Antarctica", *Metrologia*, in press, 1998.
- Jaross, G., Z. Ahmad, R. P. Cebula, and A. Krueger, "Post Launch Performance of the Meteor-3/TOMS Instrument," Ozone in the Troposphere and Stratosphere, Part 2, R. D. Hudson, ed., NASA Conference Publication 3266, 942-945, 1994.
- Jaross, G., C. Wellemeyer, C. Seftor, T. Kelly, S. Taylor, and L. Moy, "TOMS/ADEOS In Flight Calibration", RSTX-3036-701-GJ-98-002, February, 1998.
- Jaross, G., C. Wellemeyer, T. Kelly, C. Seftor, S. Taylor, L. Moy, and G. Labow, "TOMS/Earth Probe Calibration: Low Orbit Period", RSTX-3036-701-GJ-98-005, March 1998.
- Jaross, G., "TOMS FM-3 Prelaunch Calibration", "HSTX-3036-403-GJ-95-017, September 1995.
- Jaross, G., "TOMS FM-4 Prelaunch Calibration", RSTX-3036-701-GJ-98-001, February 1998.
- Kelly, T. J., "Earth Probe/TOMS Stare Mode Overpasses: Test Results and Operational Guidelines", HSTX-3036-503-TK-97-011, April 1997.
- Kelly, T. J., "MET Beating in SSBUV-4 and SSBUV-5: Correction by Software", HSTX-3036-112-TK-93-037, July 1993.
- Krueger, A. J., G. Jaross, and U. Hartmann, "Design of the ADEOS/TOMS Instrument for Ozone Trend Assessment", *Proc. SPIE*, 2583, 235-244, 1995.
- Laamann, K., and R. P. Cebula, "NOAA-11 SBUV/2 Diffuser Reflectivity Analysis: 4 Years of Input Data", HSTX-3036-112-KL-93-024, May 1993.
- Laamann, K., and R. P. Cebula, "NOAA-11 SBUV/2 Inter-Range Ratio Analysis: 4 Years of Input Data", HSTX-3036-112-KL-93-023, August 1993.
- Leitch, J. W., "SSBUV Electronic Offset Levels and Noise", HSTX-3036-212-JL-93-054, December 1993.
- Moy, L., R. Cebula, M DeLand, S. L. Taylor, and C. Wellemeyer, "NOAA-9 SBUV/2 (FM#1) Version 6.1 Calibration Report", RSTX-3036-701-LM-98-003, February 1998.

Seftor, C., G. Jaross, J. Herman, X. Gu, L. Moy, S. Taylor, C. Wellemeyer, "The Meteor 3 Total Ozone Mapping Spectrometer Version 7 Dataset: Calibration and Analysis", *J. Geophys. Res.*, 102, 19247-19256, 1997.

Steinfeld, K., M. T. DeLand, R. P. Cebula, and S. L. Taylor, "NOAA-11 SBUV/2 (FM#4) Version 6.1 Calibration Report", HSTX-3036-508-KS-97-015, August 1997.

Weiss, H., R. P. Cebula, K. Laamann, and R. D. McPeters, "Performance Evaluation of the Solar Backscatter Ultraviolet Radiometer, Model 2 (SBUV/2) Inflight Calibration System," Ozone in the Troposphere and Stratosphere, Part 2, R. D. Hudson, ed., NASA Conference Publication 3266, 931-933, 1994.

Wellemeyer, C. G., S. L. Taylor, G. Jaross, M. T. DeLand, C. J. Seftor, G. Labow, T.J. Swissler, and R. P. Cebula, Final Report on Nimbus-7 TOMS Version 7 Calibration, NASA Contractor Report 4717, NASA Goddard Space Flight Center, 48pp, March 1996.

Software Development and Maintenance

Throughout the contract period RSTX developed software systems and performed adaptive, corrective and enhancement maintenance on the TOMS, SBUV/2, and SSBUV data systems.

Major RSTX software development and maintenance activities included:

- Converted TOMS and SBUV/2 data systems from IBM MVT to IBM MVS; then from IBM MVS to VAX VMS; then from VAX VMS to SGI UNIX
- Automated TOMS data communications, science processing, and data distribution
- Developed near real-time processing systems for Meteor-3, EP, and ADEOS TOMS
- Developed L0-L3 science data processing systems for EP/TOMS and ADEOS/TOMS
- Developed ADEOS/TOMS mission operations software
- Defined and tested ADEOS TOMS science operations interfaces
- Developed TOMS Standard Products in Hierarchical Data Format (HDF)
- Implemented Version 6 SBUV/2, and Versions 6.5 and 7 TOMS, retrieval algorithms
- Colocated increased resolution terrain heights, improved cloud climatology, and new surface category codes to each TOMS field of view (all missions)
- Developed IDL image generation and product validation tools
- Developed the TOMS Web Site
- Added new products (erythemal UV, aerosol, overpass, zonal means) to the TOMS processing systems

Adaptations to accommodate changes in EP/TOMS operations (i.e. "stare mode") and orbit geometry (500 km to 740 km) were also developed and installed into the processing system.

Documentation produced by RSTX during software development and maintenance include:

Abrams, E., C. Cote, M. Forman, J. R. Herman, A. Krueger, J. Loiacono, T. Riley, J. Sissala, S. Way, R. Wessells, W. Byerly, G. Jaross, L. Pan, C. Scott, D. Harrison, and C. Gordon, "Interim Status Report on Results from the US/Russian Meteor-3/Total Ozone Mapping Spectrometer - August 15, 1991 to June 1, 1992", NASA Technical Memorandum 104576, January 1993.

Byerly, W., ADEOS/TOMS Science Operations Center Programmer's Guide, December 1997.

Byerly, W., ADEOS/TOMS Science Data Product Specification, January 1996

Byerly, W., EP/TOMS Science Data Processing Programmer's Guide, October 1997.

Abrams, E., C. Cote, M. Forman, J. R. Herman, A. Krueger, J. Loiacono, T. Riley, J. Sissala, S. Way, R. Wessells, W. Byerly, G. Jaross, L. Pan, C. Scott, D. Harrison, and C. Gordon, "Interim Status Report on Results from the US/Russian Meteor-3/Total Ozone Mapping Spectrometer - August 15, 1991 to June 1, 1992", NASA Technical Memorandum 104576, January 1993.

Krueger, A. J., G. Jaross, and W. Byerly, "TOMS Program Report", The Second ADEOS Symposium/Workshop, March 1997.

Raines, B., L. Liu, J. Stokes, B. Byerly, and C. Wellemeyer, "NOAA SBUV/2 Reprocessing System Version 6 Development", HSTX-3036-116-CW-93-029, August 1993.

Data Processing

RSTX provided data processing services for GSFC Code 916 including data ingest, QC monitoring, problem resolution, science product generation, and product verification.

Key data processing activities included:

- Level 0/1 processing of Nimbus-7 VIP telemetry
- Level 2-3 processing of Nimbus-7 SBUV, TOMS, ERB, and SAM-II
- NOAA-11 SBUV/2 Level 2 processing
- Version 6.5 reprocessing of Nimbus-7 and Meteor-3 TOMS
- Version 7 reprocessing of Nimbus-7, Meteor-3, and ADEOS TOMS
- Near real-time processing of Meteor-3, ADEOS, and EP TOMS
- Near real-time data distribution to NASDA EOC (ADEOS), NOAA NESDIS (EP), and the Internet (all)
- GSFC DAAC archival of Version 7 Nimbus, Meteor, and ADEOS TOMS products
- Transfer and conversion of TOMS and SBUV/2 data from IBM mainframe to UniTree and from Unitree to Code 916 mass storage
- Processed and provided the final reprocessing of ozone, solar, and special observation data from all eight SSBV flights, archived these data at the GSFC DAAC;
- Processed sweep mode solar spectral irradiance and discrete mode Mg II solar data from all operational SBUV/2 instruments;

Weekly processing reports were delivered to GSFC Code 916.

Algorithm Development

The RSTX algorithm development effort can be divided into SBUV and TOMS ozone algorithm development and the development of algorithms for the derivation of other atmospheric parameters. The main components of the SBUV algorithm development effort consist of:

- Enhancements to correct for SBUV/2 grating drive positioning errors.
- Enhancements to compensate for non-functional CCR on N14 SBUV/2.
- Initial development of V7 SBUV profiling algorithm.

The major component of the TOMS algorithm development was the enhancement to Version 7. The principal elements of this enhancement included:

- Use of an improved cloud height climatology and partial cloud model.
- Accounting for the effect of variations in profile shape at high solar zenith angles.
- Discarding the use of effective absorption coefficients.
- Accounting for the effects of Rotational Raman Scattering
- And additional improvements to the radiative model.

The improvements in the Version 7 algorithm provided a new level of detailed information in the algorithmic residuals. The analysis of this information lead to the improvement or development of algorithms for the retrieval of other atmospheric parameters. These include:

- Sulfur dioxide
- Cloud height
- Stratospheric volcanic aerosol
- UV radiation at the Earth surface
- Tropospheric aerosol
- Volcanic ash

RSTX analysts also supported the retrieval of Nitrous Oxide from radiances measured by SSBUV. Validation efforts based on comparison with independent measurements has also lead to involvement with algorithms for hand held radiometers and upper level climatology for in situ balloonsonde measurements.

An important aspect of documenting algorithm performance is the sensitivity study. Sensitivity in a derived parameter to effects not taken into account by the retrieval algorithm is a necessary factor in evaluating the error budget and considering enhancements to the algorithms. Over the course of the contract, a number of sensitivity studies have been performed.

Results of RSTX's algorithm development and data processing efforts are documented in the following Contractor Reports, NASA Reference Publications, and journal papers:

Bhartia, P. K., C. L. Mateer, L. E. Flynn, and C. Wellemeyer, "Algorithm for the Estimation of Vertical Ozone Profile from the Backscattered Ultraviolet (BUV) Technique", *J. Geophys. Res.*, 101, 18,793-18,806, 1996.

Caudill, T. R., D. E. Flittner, B. M. Herman, O. Torres, and R. D. McPeters, "Evaluation of the Pseudo-spherical Approximation for Backscattered Ultraviolet Radiances and Ozone Retrieval", *J. Geophys. Res.*, 102, 3881-3890, 1997.

Flynn, L.E., G.J. Labow, R.A. Beach, M.A. Rawlins, and D.E. Flittner, "Estimation of Ozone with Total Ozone Portable Spectroradiometer Instruments I. Theoretical Model and Error Analysis," *Appl. Opt.*, 35, 6076-6083, 1996.

Herman, J. R., P. K. Bhartia, A. J. Krueger, R. D. McPeters, C. G. Wellemeyer, C. J. Seftor, G. Jaross, B. M. Schlesinger, O. Torres, G. Labow, W. Byerly, S. L. Taylor, T. Swissler, R. P. Cebula, and X.-Y. Gu, Meteor-3 Total Ozone Mapping Spectrometer (TOMS) Data Products

- User's Guide, NASA Reference Publication 1393, NASA Goddard Space Flight Center, Greenbelt, MD, October 1996.
- Joiner, J., and P. K. Bhartia, "Accurate Determination of Total Ozone Using SBUV Continuous Spectral Scan Measurements", *J. Geophys. Res.*, 102, 12957-12969, 1997.
- Joiner, J., and P. K. Bhartia, "The Determination of Cloud Pressures from Rotational-Raman Scattering in Satellite Backscatter Ultraviolet Measurements", *J. Geophys. Res.*, 100, 23019-23026, 1995.
- Joiner, J., P. K. Bhartia, R. P. Cebula, E. Hilsenrath, R. D. McPeters, and H. Park, "Rotational-Raman Scattering (Ring Effect) in Satellite Backscatter Ultraviolet Measurements", *Appl. Opt.*, 34, 4513-4525, 1995.
- Krotkov, N. A., I. Sprod, I., A. J. Krueger, and P. K. Bhartia, "Analysis of Fresh Volcanic Clouds Using Radiative Transfer Modeling and TOMS Data", *IRS '96: Current Problems in Atmospheric Radiation*, Ed. by Smith and Stamnes, 468-471, 1997.
- Krotkov, N. A., P. K. Bhartia, J. Herman, E. Celarier, and T. Eck, "Estimates of Spectral UVB Irradiance from TOMS Instrument: Effects of Clouds and Aerosols", *IRS '96: Current Problems in Atmospheric Radiation*, Ed. by Smith and Stamnes, 873-876, 1997.
- Krotkov, N. A., A. J. Krueger, S. J. Schaefer, V. E. Fioletov, J. B. Kerr, "Radiative Transfer Modeling Of The Ground-Based And Satellite SO₂ And Ash Retrievals In Volcanic Clouds", *9th Conference on Atmospheric Radiation*, 2-7 February, Long Beach, California, 139-143, 1997.
- Krotkov, N. A., A. J. Krueger, P. K. Bhartia, "Ultraviolet Optical Model Of Volcanic Clouds For Remote Sensing Of Ash And Sulfur Dioxide", *J. Geophys. Res.*, 102, 21891-21904, 1997.
- Krueger, A. J., L. S. Walter, P. K. Bhartia, C. C. Schnetzler, N. A. Krotkov, I. Sprod, and G. J. S. Bluth, "Volcanic Sulphur Dioxide Measurements from the Total Ozone Mapping Spectrometer Instruments", *J. Geophys. Res.*, 100, 14057-14076, 1995.
- Labow, G. J., L. E. Flynn, M. A. Rawlins, R. A. Beach, C. A. Simmons, and C. M. Schubert, "Estimating Ozone with Total Ozone Portable Instruments II. Practical Operation and Comparisons," *Appl. Opt.*, 35, 6084-6089, 1996.
- McPeters, R.D., P.K. Bhartia, A.J. Krueger, J. R. Herman, B. M. Schlesinger, C. G. Wellemeyer, C. J. Seftor, G. Jaross, S. L. Taylor, T. Swissler, O. Torres, G. Labow, W. Byerly, and R. P. Cebula, Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) Data Products User's Guide, NASA Reference Publication 1384, April 1996.
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Data Validation and Analysis of Science Products

Data validation is closely linked to algorithm development. All of the algorithm development work cited above has been supported by RSTX through both external and internal validation. Data from the various BUUV instruments including:

- BUUV (N4 BUUV, N7 SBUV, N9 SBUV2, N11 SBUV2, N14 SBUV2 and SSBUV)
- TOMS (N7, M3, ADEOS, and EP)

Have been validated based on comparisons with measurements and radiances simulated based on measurements from independent instruments including:

- Ground based (Dobson, Umkehr, Brewer, Microtops, and sun photometer)
- In situ (Balloonsonde and air craft missions)
- Satellites (SAGE, SME, MLS, HALOE, GOME, CLAES, TOVS, AVHRR, GOES)

RSTX personnel have also worked to support ground measurements made by SBUV2 pre-flight. Also we have begun an internal ground measurement program based on commercial spectrometers and photometers for use in validating the new surface ultraviolet product.

Some of the more valuable forms of validation have been derived from internal analysis of BUV and TOMS measurements. Many of these techniques have been used by RSTX to calibrate BUV instruments when traditional inflight calibration systems have been unavailable or have failed. These internal methods include:

- Pair justification
- Scene stabilization
- Langley analysis
- Spectral discrimination
- Background SOI
- Radiance and irradiance based comparisons with other BUV measurement systems.

The solar measurements are primarily made by the BUV instruments to provide I/F for the derivation of ozone, but they are a valuable measurement in and of themselves. A significant effort has gone into the analysis and validation of the solar flux measurements. Key accomplishments and findings included:

- Created and maintained the SBUV/2-SSBUV solar irradiance web page (<http://ssbuw.nasa.gsfc.gov/solar.html>);
- Analyzed solar irradiance data from all eight SSBUV missions, compared these data to other Space Shuttle and satellite-borne solar instruments, and used these data to provide a correction for long-term drift in the NOAA-11 SBUV/2 solar data.
- Analyzed special observation data from the SSBUV-4 through SSBUV-8 missions, including NO, SO₂, lunar albedo, and modified ozone retrieval data sets.
- Used SSBUV data to validate GOME ozone and solar data.
- ETC

As a part of the validation process, a certain amount of analysis has been carried out by RSTX personnel in support of the contract. These studies of derived parameters include analysis of global distribution, long-term trends, and local episodic events.

Results of RSTX's data validation and analysis of science products are documented in the following Contractor Reports, NASA Reference Publications, and journal papers:

Aikin, A. C., R. D. McPeters, T. Miles, and L. E. Flynn, "Intercomparison of UV Spectrometer and Polarimeter on SMM and Stratospheric Aerosol and Gas Experiment II Ozone Profiles and Trends in The Lower Mesosphere", *J. Geophys. Res.*, **101**, 9023-9029, 1996.

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